B.S.T.J. BRIEFS

A Silicon Diode Microwave Oscillator

By R. L. JOHNSTON, B. C. DE LOACH, Jr., and B. G. COHEN

(Manuscript received December 28, 1964)

Microwave oscillations have been obtained on a pulse basis from silicon diodes. This brief reports fabrication details and performance data. The similarities of this device to that proposed by Read[1] are discussed.

The diodes were made by diffusing boron to a depth of approximately 25 μ into one face of a slice of 0.15 ohm-cm n-type silicon, and then lapping the other face to a final slice thickness of 175 μ. Electroless nickel was then applied to both faces and sintered at 800°C for 5 minutes in N_2. Nickel was then replated and followed by a final plate of gold. The slice was then ultrasonically sectioned into squares 125 μ $\times$ 125 μ. To remove cutting damage the "wafers" were etched for about 10 seconds in CP-8 (3 parts HNO_3, 1 part HF), and were then incorporated into a microwave encapsulation. A sketch of a wafer before encapsulation is shown in Fig. 1.

Oscillations are observed when a critical reverse voltage is applied to the diode. This voltage has been observed on a variety of samples to correspond to that required to produce enough reverse current to create an electric field on the order of 2 kv/cm in the 150-μ n-type region. A typical reverse *V-I* characteristic obtained on a pulse basis using a sampling oscilloscope is shown in Fig. 1. On samples which were lapped to reduce the drift region length from 150 μ to 75 μ, the required voltage in excess of the avalanche voltage was halved. Voltages in excess of threshold produce more output until a maximum is reached. Some lower frequencies in the 1-2-gc region exhibited several maxima, but the higber frequencies (12 and 24 gc) had but one.

The fact that voltages considerably in excess of the "breakdown" voltage are employed tends to deemphasize the role of microplasmas and nonuniformities in the junction and thus contributes to the ease of fabrication of tbese devices.

The diodes were tested in eitber a coaxial system, for the lower frequencies ($f \lesssim 12$ gc), or in a reduced-heigbt waveguide for the higher frequencies (8–24 gc). The mounts incorporated a bypass capacitor which allowed the introduction of a video pulse to power the diode.

Microwave oscillations (when present) were coupled to a spectrum analyzer.

The operation of a particular sample of the geometry shown in Fig. 1 will be described. It was placed in the coaxial circuit and driven with a 2 μsec pulse at a 10-kc repetition rate. When the applied pulse voltage reached a critical value, microwave power output was observed. Power was obtainable over a wide range of frequencies, but some frequencies had particularly high amplitudes. A plot of some of these "high points" is presented in Fig. 2. Included in this figure are two points obtained from a similar sample operated in the waveguide mount. Fig. 2 can also be interpreted as a rough plot of efficiency versus frequency, since pulse powers between 15 and 30 watts were employed for all these points. The 80 mw obtained at 12 gc represents 0.5 per cent efficiency. Similar samples have been operated with duty cycles of 25 per cent (to burnout).

The higher-frequency operation for which the efficiencies are on the order of 0.5 per cent is most likely an oscillation involving primarily the space charge depletion width for the drift space. The extent of this region is of the order of that predicted by Read for this frequency of operation. The requirement of 2 kv/cm in the 150-μ region for this operation most likely assures that fields greater than this exist across

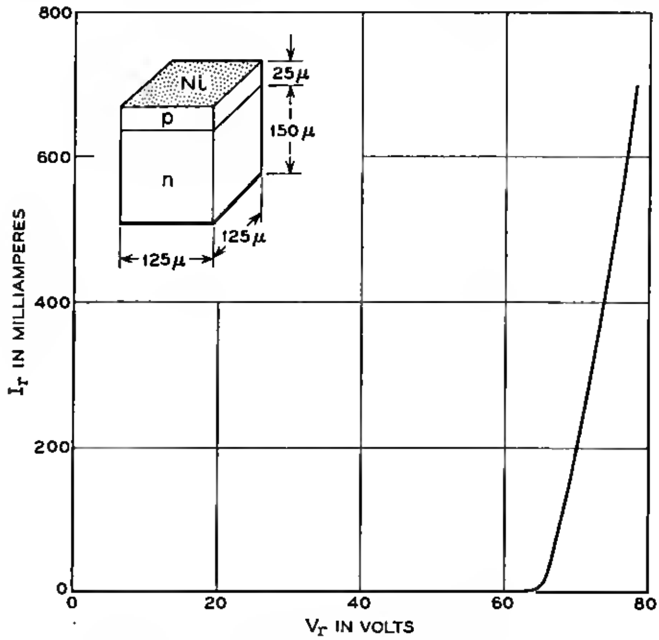

Fig. 1 — A typical sample and its V-I curve.

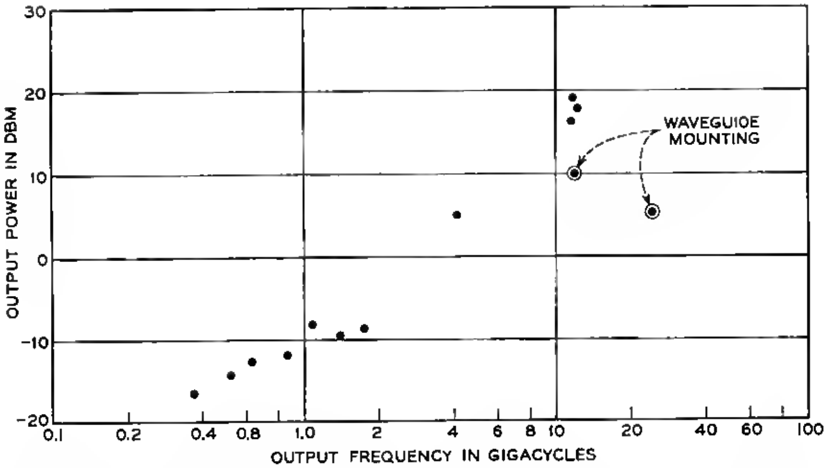

Fig. 2 — Output power vs frequency for a diode in a coaxial circuit and one in a rectangular waveguide circuit.

the depletion region. This added length should then be removable without changing the character of these oscillations and indeed should enhance the efficiency of operation. The circuitry employed in obtaining the higher-frequency microwave power was crude, and thus the power obtained in the X and K band regions (12 and 24 gc) should be taken as a poor lower limit of that available.

We are uncertain at present as to the explanation for the lower-frequency points exhibited in Fig. 2. The 2 kv/cm field required is high enough that the mobility has decreased in the 150-μ region. The usual dielectric relaxation time of this material of 10^{-13} sec is thus increased and some bunching of charge is preserved in the region, with charge transport (1×10^7 cm/sec) becoming significant. This "stiffening" of the conductive region could allow it to function as a drift region in the same manner as does the swept region in the above. The approximately linear increase in output power with frequency in this region could then be due to a redistribution of ac field between the space charge depletion layer capacity and the ac impedance of the drift region. That this mechanism is not very effectual can be deduced from the efficiencies of some 1×10^{-3} per cent in the region up to 2 gc.

Many helpful discussions with R. M. Ryder and J. C. Irvin are gratefully acknowledged.

Note Added in Proof:

Subsequent to the pulsed microwave operations described in this

Brief, Lee et al.[2] have obtained low-frequency cw operation in a silicon diode with a npπp structure closely approximating the structures described by Read.[1] Still more recently, continuous microwave oscillations have been obtained by Johnston and De Loach[3] in structures similar to those described herein.

REFERENCES

1. Read, W. T., A Proposed High-Frequency Negative-Resistance Diode, B.S.T.J., *37*, pp. 401–446.
2. Lee, C. A., Batdorf, R. L., Wiegmann, W., and Kaminsky, G., to be published.
3. Johnston, R. L., and De Loach, B. C., to be published.